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N64-24529

Code none

SOLVING MECHANICAL PROBLEMS IN ION-ENGINE DESIGN

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Most of the credit for the brisk progress of ion engines has been earned by analytic and experimental researchers, but a share of the laurels must also go to design engineers. Four ion-rocket research projects at NASA-Lewis provide cases in point.

In one early-model ion engine, the problem was to reduce fuel waste. The engine's ionization section was a through-feed, strip type; the cesium molecules were ionized by contact with heated strips of tungsten. Unfortunately, the spaces between the strips allowed a large percentage of the neutral molecules to pass through the ionization section.

A flow-restricting, porous ionizer was hit upon as a good way to cut the cesium loss. The probability of ionization was to be boosted by forcing the propellant through a heated, porous tungsten plate with an average pore size of less than one micron.

The design specs for modifying the engine for use with a porous ionizer required that the new ionization section be interchangeable with the existing acceleration and propellant supply components and use a 1-by-6-in. porous tungsten slab 0.002 in. thick. It was also desirable to control the porosity of the material to keep the propellant flow and resistive heating uniform.

Tungsten powders of 1-10-micron particle diameter were pressed into slabs in a rectangular die. The resulting compacts were sintered in hydrogen at a temperature that bonded the powder particles together without entirely closing the intervening voids.

High contact pressures needed

To produce the proper ionization, the slabs would have to be heated to at least 2000 F in a vacuum of 10^{-6} torr. Since the slab's resistance was to be used for heating and about 250 amp of heating current would be needed, considerable contact pressures would be involved.

The slabs couldn't be joined to any other engine components and had to be clamped in place. To electrically and thermally isolate the metallic clamping components from the resistance heating circuit, a plasma-sprayed coating of high-purity alumina was put on the adjoining surfaces and ground to a smooth, flat sealing surface having a high dielectric constant and low thermal conductivity. Around the propellant flow passage annealed nickel-foil gaskets made a gastight seal on either side of the slabs.

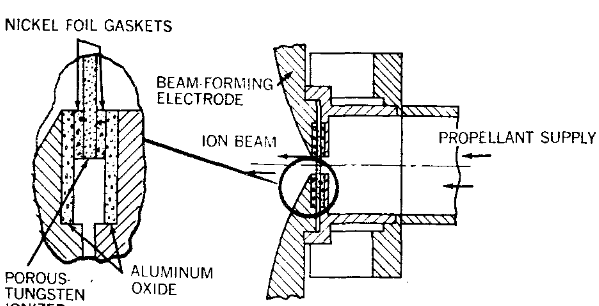
The porous ionizer markedly improved the engine's utilization of propellant. Although the brittle slabs often broke during assembly or operation and a great deal of heat was lost by conduction through the metallic mass of the assembly, the balance of the approach worked out well. Eventually ways were found to braze and electron-beam weld the porous slabs to various materials and shapes, simplifying the design. A 10-unit engine is now undergoing preliminary tests.

A later engine concept depended on preventing the deflection of fine, closely spaced wires that formed its accelerating system. This design offered simplicity, lightness, high efficiency, and high ion-beam current density at moderate accelerating potentials.

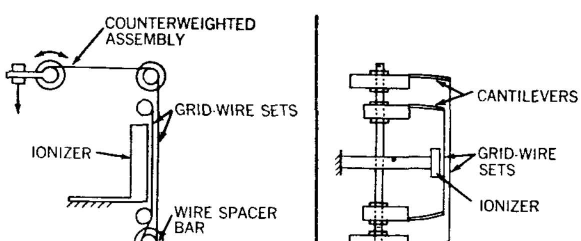
Two parallel sets of 0.0029-in.-diameter tantalum wires on a 0.039-in. pitch were spaced 1 mm apart. Since the wire sets and the ionizer were to be kept at different potentials and, in the case of the first wire set, at opposite polarity, electrostatic forces would tend to deflect the wires. In addition, reaction to the engine's thrust would also tend to deflect the wires, and heat from the nearby ionizer would make the wires expand, resulting in sag.

The original engine used a counterweighted tension system to keep the grids taut. This system was plagued by friction in the spacer bars through which the wires passed. Unable to move freely, the wires sagged, eventually allowing short-circuiting between sets.

A frictionless cantilever technique seemed like the obvious answer to friction troubles. Each end of the 0.005-in.-diameter wires was resistance-welded to a thin tantalum cantilever to form the grid-wire sets. Separating the holding fixtures to which the cantilevers were attached gave the sets their initial tension. As the wires expanded with a temperature rise, the cantilevers unbent and took up the slack.



POROUS *tungsten slab, used as ionizer, is insulated from adjoining surfaces by plasma-sprayed alumina coating. Gastight seal is provided by nickel foil.*



GRID-WIRE *ion-accelerator ran into trouble when its counterweighted tension-compensating assembly, using grid-wire sets produced by winding one continuous wire (left), was plagued by friction. So grid wire sets were made of individual strands and a cantilever system was developed to keep them taut (right).*

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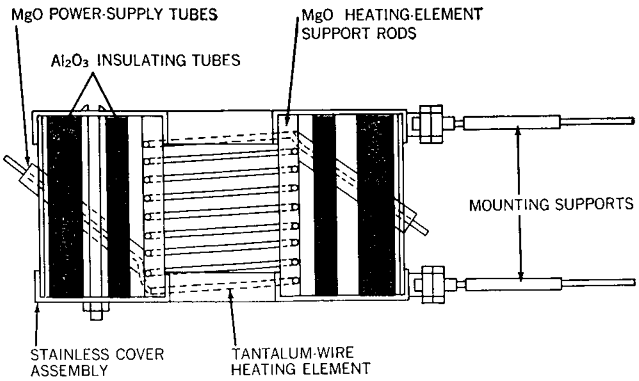
Designing the cantilever system was tricky. Maximum deflection was the sum of two components: that associated with resisting the effect of the applied load, and that required to compensate for the tension loss due to differential thermal expansion between the grid wires and the cantilever holding-fixture. It was necessary to keep wire axial stress and cantilever bending stress below their yield values throughout the operating temperature range of 2000 F while keeping the proper axial tension in the wires—a formidable task considering that the yield strength of tantalum sheet, for example, decreases by a factor of about eight over that range.

The problem was solved by manipulating cantilever thickness, length, and width; short circuiting due to sagging wires was ended.



WIRE-WOUND *radiation heater—a simple, effective, and rugged way to keep an ionizer disk heated to a temperature of 2300 F.*

Device to measure thrust

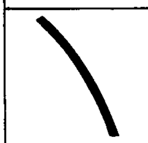
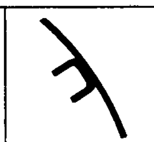
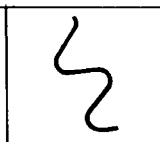
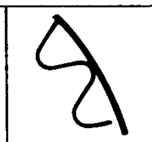
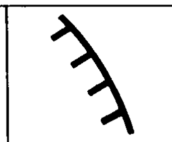
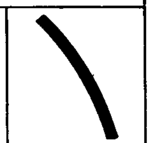
Another contribution to the progress of the ion engine was made by engineers at NASA-Lewis in response to a request for a simple device that could be used in direct measurements of thrust and in studying the makeup of the ion beam itself. They designed an ionizer with a porous tungsten disk brazed into the end of an easily heated refractory-metal tube. The tube was heated by energy radiated from a nearby incandescent element; the heat was conducted through the walls of the tube to the ionizer disk. The ions were accelerated by a previously developed system, and electrons for neutralization were supplied by a heated tungsten wire strung across the path of the exit beam.

Two heaters were designed for possible use in this engine: one used a split cylinder as a resistance element, the other a closely spaced wire helix. Space was limited in this engine, and the cylinder used it more effectively but it also required a much larger current than a comparable helical element. To minimize current requirements, a wire-wound element was chosen.

Since thermal analysis indicated the element would have to operate at 3000 F to keep the ionizer heated to 2300 F, tungsten and molybdenum, which become brittle once heated above 2000 F, did not appear satisfactory and tantalum was adopted. Magnesium oxide was used for the support rods. At first, ceramic tubing was used for the outer insulation, but it was found that using fine alumina powder cut the heat loss considerably.

This heater design is easy to make and maintain. Rugged and cheap, it is highly effective in transferring heat to the emitter tube with low external heat loss.

LOAD RESULTS FOR SIX STRUCTURAL HOUSINGS

						
	Simple Wall (0.008 in.)	Simple Wall With Four Stiffeners 90 Deg Apart	Simple Corrugated Cylinder	Simple Wall With Corrugated Inner Wall	Simple Wall With Stiffeners	Simple Wall (0.016 in.)
Wall thickness (in.)	0.008	0.008	0.008	0.008	0.008	0.016
Yield load (lb)	900	1,500	2,000	8,000	10,000	2,000
Configuration weight (lb)	0.22	0.33	0.47	0.51	0.59	0.36
Yield load-weight ratio	4,100	4,500	4,300	15,700	16,900	5,600
Cross section area (sq in.)	0.13	0.15	0.18	0.31	0.38	0.25
Apparent failure stress (psi)	6,900	10,000	11,100	25,800	26,300	8,000
Compressive load at yielding (theoretical, lb)	5,200	6,000	7,200	12,400	15,200	10,000
Buckling load (theoretical, lb)	3,500	4,100	4,800	8,300	10,200	13,500

Designing the cylindrical body

In still another program, the problem was to design a flyable successor to the original research model of the electron-bombardment ion engine. Thrust is produced in this engine by the ionization of gaseous mercury as it's bombarded by high-speed electrons emitted from an incandescent filament located within the ionization chamber.

The cylindrical body of the engine seemed a logical place to start the mechanical design analysis, since the body would bear the brunt of the 40-g launch loading. Besides functioning as a propellant supply duct and as the ion chamber, the body was also one of the main structural components. It therefore had to be rigid as well as light. Flanges were put on either end, both to improve rigidity and to provide mounting points for allied components.

Although no stiffeners could be used on the bore, the outside wall configuration could be chosen freely. Six test specimens were therefore made from 304 stainless sheet with a rated tensile yield strength of 40,000 psi. A 2000-lb axial load capability was set for the cylinder.

The specimens were loaded by a standard compression test machine, and yielding was determined visually. Only order-of-magnitude results were gathered.

Four configurations met the 2000-lb minimum-load requirement. Three of the cylindrical pieces had an 0.008-in. wall—one with an added inner wall of U-shaped stiffeners, one simply corrugated, and one having an added corrugated inner wall. The fourth was a simple wall twice as thick (0.016 in.). This last configuration met the load requirement with the least weight penalty and it was therefore used in the flight engine. The engine has successfully qualified in a full-scale vibration test; a similar one will be aboard a soon-to-be-launched space capsule.